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(54) Solid liquid inter-diffusion bonding for ring laser gyroscopes

(57) A method for bonding a gyroscope component to a gyroscope body using the solid liquid Inter Diffusion (SLID) process. The resulting bond structure has a larger operating range than the bonding materials used to create to bond. Mating material layers may be added to the bond to improve bonding between the bonding materials and the component and between the bonding materials and the gyroscope body.

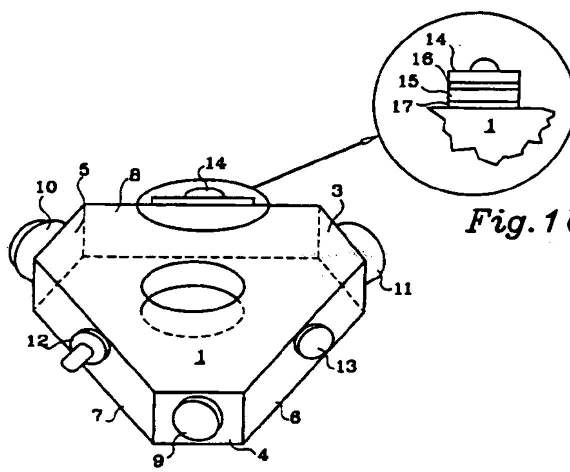

Fig. 1b

Fig. 1a

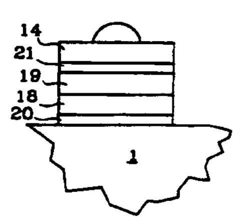

Fig. 1c

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Description

BACKGROUND OF THE INVENTION

[0001] This invention relates generally to bonding methods for use with materials such as glass, quartz, metal, ceramic and the like. More specifically, the invention relates to a method for bonding ring laser gyroscope components to the gyroscope body.

[0002] In one common form of compact ring laser gyroscope, a block comprising a glass, quartz, ceramic or similar material and having a low coefficient of thermal expansion (CTE) forms the body of the gyroscope. A number of components typically composed of glass or metal, such as electrodes, mirrors, and readout apparatus, are attached to the gyroscope body. Sealed passages in the body allow optical communication among the various components. The passages of the gyroscope body are filled with a lazing gas which lazes upon current being applied to the gyroscope.

[0003] A cathode and two anode components are used to create the beams of laser light traveling in opposing directions through the gyroscope body. The cathode and anodes may be composed of aluminum, steel, nickel or other metal which meets the design requirements for the gyroscope. The other components attached to the gyroscope may be glass mirrors, or may be glass-metal components which, for instance, allow adjustment of gyroscope mirror position to improve gyroscope performance.

[0004] The life and accuracy of the gyroscope is largely effected by the ability of the components to be properly bonded to the gyroscope body in such a way as to prevent escape of lazing gas, or contamination of the gyroscope passages with foreign gasses. In an ideal case, the seal should be hermetic, meaning that a negligible amount of gas is exchanged between the passages in the gyroscope body and the atmosphere during the life of the gyroscope. Thus the method used to seal the components to the gyroscope body is critical to the performance of the gyroscope.

[0005] The bonding method may also effect the operating range of the gyroscope, depending on the conditions under which the bonding materials degrade. Of particular concern are bonding materials having melting temperatures which limit the possible applications of the gyroscope (i.e. oil drilling, high speed/altitude aircraft, etc.) As another concern, the bonding of components to the gyroscope body ideally should not interfere with or alter previously completed processing steps, nor limit subsequent processing steps.

[0006] With these considerations in mind, numerous methods of bonding the components to the gyroscope body have been attempted, each with some measure of success. High temperature epoxy for example has been used as an effective material for glass-glass bonds. Indium or other soft metals have typically been popular for glass-metal bonds. Both have been effective in part because they are flexible enough to compensate for the differences in the CTE of the two materials being bonded. Other bonding methods, such as graded bonds and the use of glass frits, which attempt to match the CTE of the two materials to be bonded together, have also been successful.

[0007] Unfortunately, the epoxy and soft metal bonding techniques, due to the flexibility of the bond materials, tend to allow outgassing or fail to provide a bond capable of the types of pressures typically desired for high-end gyroscope devices. Indium in particular "squishes" out of the bonding area with repeated use of the device, eventually causing failure of the gyroscope. Neither epoxy or soft metal allow the gyroscope to be operated at high temperatures, since the limit of the gyroscopes range of operation is the melting temperature of the bonding material. In some cases an even lower limit is caused if the bonding material begins to degrade below its melting temperature. These same limits will effect the types of processing the gyroscope may undergo subsequent to formation of the bond.

[0008] Glass frits, which are used for bonding two identical materials, or materials with nearly identical CTE's together, require less cleaning and preparation of the bonding surfaces than required when forming indium seals. The use of glass frits is known to produce consistent and inexpensive hermetic seals. Unfortunately, the glass frit bonding process requires an elevated temperature which substantially limits the types of processing which can be done near the area of the bond prior to the bonding process. Furthermore, there is an inverse relationship between frit bonding temperature and the CTE for the frits used, which means that frits with low CTE, near that of the typical gyroscope body materials, have such high processing temperatures that they exceed the thermal limits of the gyroscope body. Thus, use of frits usually introduces a thermal mismatch into the gyroscope since a comprise must be made between bonding temperature and the CTE of the frit.

[0009] As a last point, gyroscope construction would be simpler if a single bonding material could be used to bond all components to the gyroscope body. Presently, individual bond techniques are used based on the type of component to be bonded, since no common bonding technique is known for all component types.

SUMMARY OF THE INVENTION

[0010] The present invention describes a process for producing a bond structure which allows a ring laser gyroscope to be used at elevated temperatures without bond degradation, and also may be used for all components to be bonded to the gyroscope body. The process has the added advantage that it does not require elevated temperatures or pressures during processing to achieve these results.

[0011] In the first and second steps of the applicant's invention, a first bonding material is applied over the

mating surface of the gyroscope body and a second bonding material is applied over the mating surface of the component. The bonding materials are chosen so that they will form an alloy when placed in contact at a temperature below the melting temperature of either bonding material, while the alloy created will have a melting temperature above the melting temperature of the lower of either bonding material. In the third step of the applicants' invention the first bonding material layer is contacted to the second bonding material layer at a temperature less than the melting temperature of either bonding material to cause formation of the alloy.

[0012] The effectiveness of the process can be improved by forming a mating material layer between the gyroscope body and the first bonding material layer, and between the component and second bonding material layer. The mating material is chosen based on its ability to bond better with the alloy than either the gyroscope body or the component bond with the alloy.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013]

Fig. 1a shows a gyroscope suited for application of the applicants' invention.
Fig 1b shows an expanded view of the bond between one of the components and the gyroscope body according to the applicants' invention.
Fig 1c shows an expanded view of a modified bond between one of the components and the gyroscope body according to the applicants' invention.
Fig. 2a - 2c are process diagrams showing the various stages of one method of processing the substrate according to the applicant's invention.
Fig. 3a - 3c are process diagrams showing the various stages of one method of processing the component according to the applicant's invention.
Figure 4a shows the critical processing step for the applicants' invention.
Figure 4b shows the final structure created by the applicants' preferred embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0014] Figure 1a shows one form of gyroscope suited for application of the applicant's invention. Gyroscope body 1 is generally triangular in shape. The gyroscope body is formed of a glass or glass-like material, and typically has a low CTE. Passages (not shown) within the gyroscope body link openings in the gyroscope body at each corner. The corners of the gyroscope body are truncated to provide mating surfaces 3, 4 and 5 for a component at each corner. The opening at each corner (not shown) allows optical communication between components. The sides of the gyroscope body provide three remaining mating surfaces 6, 7 and 8. In the gyroscope shown, mating surfaces 4 and 5 have mated thereto adjustable mirror units 9 and 10 comprised of a Zerodur material. Mating surface 3 has mated thereto a readout mirror 11, also of Zerodur. On the sides of the gyroscope, cathode 12 is mated to mating surface 7, and anodes 13 and 14 are mated to mating surfaces 6 and 8, respectively. The cathode and anodes are composed of an aluminum-type material. Sub-passages (not shown) are connected to the passages between the corners of the gyroscope body, and optically connect the cathode and anodes to each other and to the components at the corners.

[0015] Figure 1b shows a detailed view of one of the bonds, contemplated by the applicants. Between component 14 and substrate 1, is an alloy layer 15. The alloy is sandwiched by two layers of mating material 16 and 17. In the preferred embodiment, the alloy material is a gold-indium alloy and the mating material is chrome. Figure 1c shows a alternate structure created by the applicant's method. In this structure, a layer of one of the bonding materials 18 used to form the alloy and a layer of alloy 19 are sandwiched between two layers of chrome 20 and 21. The excess bonding material in the bond, as will be described shortly, although not necessary, ensures that the bond will have the best possible operating range.

[0016] While a detailed view of only one of the bonds is shown, the applicant intends that the detailed views of figures 1b or 1c would be the same for any of the component-substrate bonds of gyroscope 1.

[0017] Mating material layers 16 and 17 in figure 1b and mating material layers 20 and 21 in figure 1c are preferable, but may be optional if the bonding characteristics of the component and the substrate to the alloy are acceptable without these layers. In the preferred embodiment, which uses a gold-indium alloy and a Zerodur substrate, the chrome is preferably included, however.

[0018] A more detailed description of the characteristics of various layers is now provided. Gyroscope body 1, which may be called, and will be referred to as the substrate may be quartz, glass, or another glass-like substance which has a low CTE suitable for ring laser gyroscopes. Two common materials used in the area of ring laser gyroscopes are Zerodur and Cervit. In the preferred embodiment the gyroscope body is formed from Zerodur.

[0019] Mating material layers 16, 17 and 20, 21, as indicated, are chrome in the preferred embodiment. The chrome layer, provides excellent bonding characteristics to Zerodur, the alloy materials --gold and indium, and the component materials --aluminum and Zerodur. Rather than attempting to match the CTE of the materials in the bond, the chrome layer thickness is chosen to be thin enough so that the stress on the chrome caused by CTE discrepancies is negligible. It is contemplated that the chrome may be replaced with another mating material having similar properties to that of chrome. The

chosen mating material should however, exhibit better bonding characteristics to the materials it is adjacent to, than the adjacent materials would have to each other. For example, in the preferred embodiment, gold and indium do not bond well to glass. Chrome on the other hand bonds well to both these materials.

[0020] In a proper structure, the mating material layer may be eliminated entirely if the quality of the bond between the bonding materials used and the glass substrate and the component meet the designer's quality requirements. A number of mating materials may also be employed if a single material cannot be found which bonds well to both adjacent materials. Use of graded mating materials, which allow matching of CTE's is also contemplated.

[0021] The alloy layer is composed of first and second bonding materials. Typically, one of the two materials will have a melting temperature substantially lower than the other. In the applicants' planned method, one of the bonding materials will diffuse into the other at a temperature below the melting temperature of either bonding material. The alloy produced will have a melting temperature higher than the melting temperature of the bonding material having the low melting temperature.

[0022] For, example, gold-indium is the preferred composition of the alloy layer. The melting temperature of gold is 1064°C and the melting temperature of the indium is 156°C. If the two are mated at approximately 40°C to 90°C, one will diffuse into the other to form an alloy having a melting temperature of at least 232°C but which may be as high as 450°C, significantly above the melting temperature of Indium. As will be described later, the alloy layer forms by a so called Solid Liquid Inter-Diffusion (SLID) process, not previously contemplated in the ring laser gyroscope field.

[0023] Other materials which may be used for the alloy may include combinations of gold-silver, silver-lead or tin-indium or other combinations which are adaptable to a SLID process. Material for the components may include glass similar to the material 18 of the substrate aluminum or aluminum containing metals, or other materials. In the preferred embodiment, the components are variously comprised of aluminum and Zerodur.

[0024] While the structure depicted in Figure 1b is the ideal structure, Figure 1c depicts a more realistic structure, based on current processing technologies. A layer of either bonding material will be formed adjacent the alloy layer 19 and one of the mating material layers 20 or 21 during processing. In Fig. 1c, the bonding material layer, indicated by numeral 18, is shown as formed between layers 19 and 20. This layer is due to the planned exhaustion of one of the bonding materials before exhaustion of the other bonding material during bond formation.

[0025] By making sure that the exhausted bonding material is the bonding material having the lowest melting temperature, the operating range of the bond, and thus the gyroscope is increased, since the bonding process ensures that the lowest melting temperature material is fully consumed into the alloy. This makes the bond usable to near the melting temperature of the alloy.

[0026] As an example, in the preferred embodiment, the alloy is comprised of gold and indium. Indium has a melting temperature of 156°C and gold has a melting temperature of 1064°C. Thus, when selecting bonding material thickness, the designer selects the gold layer to be of sufficient thickness to guarantee that the indium is completely diffused. The margin of error used to ensure this occurs results in a thin layer of gold which is not diffused with indium.

[0027] A similar process should be used with other compounds chosen for the alloy. For example, a lead-silver bond using the applicants' technique should include excess gold to prevent a layer of lead in the bond. For tin-indium, excess tin should be used to prevent a layer of indium.

[0028] A preferred method of the applicant's invention is now described. Initially, the substrate and the components undergo separate processing. Figures 2a - 2c show the steps in the preferred method of processing the gyroscope body or substrate according to the applicant's invention. Substrate 10 is prepared for processing as is known in the art, such as by cleaning and polishing. The substrate is subsequently vacuum deposited with chrome layer 11. Typical thickness for this layer may be 100Å, but as indicated earlier, the thickness of the chrome layer is important only insofar as it is negligibly affected by thermal expansion. A layer of gold 12 is next deposited on chrome layer 11 of approximately 500Å by vacuum deposition.

[0029] Additions of layers which form the structure of the applicants' invention herein described need not be produced by vacuum deposition. The process used should however produce homogeneous layers free of defects which would reduce the layers' effectiveness as a seal. It is for instance contemplated that vacuum deposition techniques such as electron beam vacuum deposition process, sputtering processes, CVD processes, MOCVD processes or the like, are all possible processes for forming the necessary layers.

[0030] Processing similar to that applied to the substrate occurs for the component. Referring to figures 3a - 3c, a component 20 is prepared for processing as is known in the art. The component is subsequently vacuum deposited with chrome layer 21, having a similar thickness to that of the chrome layer 11 on the substrate. A layer of indium 22 is deposited on chrome layer 21 of approximately 250Å. Due the low melting temperature of the indium, it is necessary for the gold layer to be sufficiently thick to ensure absorption all of the indium. This requirement, as indicated earlier, prevents a layer of indium from remaining in the bond after processing. The ratio which has been determined to be effective is a 2:1 ratio of gold to indium.

[0031] In the final and crucial step of the process,

shown in Figure 4a, the component-chrome-indium structure is pressed against the substrate-chrome-gold structure at slightly higher than atmospheric pressure, and at a temperature between 40°C and 90°C (below the melting temperature indium), for approximately twelve hours.

[0032] The specified pressure and time given for the bonding process are not critical to the process itself however. The critical aspect of the process is the temperature used. Chemically, the temperature chosen should raise the area of contact between gold layer 12 and indium layer 22 during the final processing step above the melting temperature of the eutectic binary alloy of the two compounds. One of skill in the art may recognize this final step is a Solid liquid Inter Diffusion (SLID) process. For a more complete understanding of SLID bonding techniques, reference is made to: "Applications of Solid Liquid Inter Diffusion (SLID) bonding integrated-circuit applications", by L. Bernstein et al., Transaction of the Metallurgical Society, vol. 236, Mar. 1966, pp. 405-412. Furthermore, U.S. Patent Number 5,106,009 to Humpston et al. is here hereby incorporated by reference as describing several possible SLID alloys and the suggested processing conditions for those alloys. It is noted however, that use of the above described steps, without further information, are sufficient for one of skill in the art to practice the applicants' invention.

[0033] Processing the substrate and component may occur simultaneously or the two may be processed sequentially. Also, cleaning and preparation of surfaces in the process have been omitted since normal methods understood by those skilled in the art would be used. For example, is it known that the substrate and the component surfaces should be sufficiently clear of impurities to allow an effective bond to the chrome, but do not require the cleaning necessary for an optical contact.

[0034] Figure 4b shows the structure resulting from the preferred method of the applicant's invention. An alloy layer 30, is formed, a portion of gold layer 12 remains, and indium layer 22 of Fig. 4a has been absorbed completely into alloy layer 30.

[0035] Those skilled in the art will recognize that only the preferred embodiment of the present invention has been disclosed herein, and that the embodiment may be altered and modified without departing from the true spirit and scope of the invention as defined in the accompanying claims. Specifically, while gold and indium have been described as the materials of choice for use in the applicant's invention, other alloys mentioned may also be used if bonding process temperatures are chosen which are suitable for the selected bonding materials.

Claims

1. In a ring laser gyroscope, a method of forming a bond between the mating surfaces of a substrate and a component, using a first bonding material having a first melting temperature and a second bonding material having a second melting temperature comprising the steps of:

   (a) depositing one of said first and second bonding materials on the mating surface of the substrate;
   (b) depositing the other of said first and second bonding materials on the mating surface of the component; and,
   (c) contacting the first bonding material to the second bonding material at a temperature below the melting temperature of either the first or second bonding materials, the first and second bonding materials thereby forming an alloy having a higher melting temperature than the lowest melting temperature of the first and second bonding materials.

2. The method according to claim 1 wherein step of contacting the first bonding material to the second bonding material comprises a SLID process.

3. The method according to claim 1 or 2 wherein the first and second bonding materials are selected from the group consisting of:

   gold-indium, tin-indium, gold-silver or lead-silver.

4. The method according to any preceding claim 1 wherein said first bonding material is provided in excess of the amount necessary to alloy with the second bonding material, thereby leaving a layer of said first bonding material subsequent to bonding, the first bonding material having a higher melting temperature than the second bonding material.

5. The method according to any preceding claim 1 wherein the step of contacting the first bonding material to the second bonding material occurs at atmospheric pressure.

6. The method according to any preceding claim, comprising the steps of:

   (a) depositing a layer of a first mating material on the mating surface of the substrate, the first mating material exhibiting improved bonding to layers adjacent to it than the adjacent layers would exhibit to each other;
   (b) depositing a layer of a second mating material on the mating surface of the component, the second mating material exhibiting improved bonding to layers adjacent to it than the adjacent layers would exhibit to each other;
   (c) depositing a layer of a one of said first and

second bonding materials on one of the mating material layers;

(d) depositing a layer of the other of said first and second bonding material on the other mating material layer; and,

(e) contacting the first bonding material to the second bonding material at a temperature below the melting temperature of either the first or second bonding material, such that the first and second bonding materials form an alloy having a higher melting temperature than either the first and second bonding materials.

7. The method according to claim 6 wherein the first and second mating materials are chrome, the thickness of the chrome in the bond such that the chrome layer is negligibly affected by thermal expansion.

8. The method according to claim 6 or 7 wherein: the first and second mating materials are chrome, the thickness of the chrome in the

bond such that the chrome layer is negligibly affected by thermal expansion; and the first and second bonding materials are gold and indium.

9. A bond structure for use in a ring laser gyroscope between the gyroscope body and one or more components bonded to the gyroscope body comprising an alloy layer formed from a first bonding material having a first melting temperature, and second bonding material having a second melting temperature lower than the first melting temperature, the alloy of the first and second bonding materials having a melting temperature higher than the melting temperature of the second bonding material, and the alloy formed at a temperature below the melting temperature of either the first or second bonding materials.

10. The bond structure according to claim 9 further comprising a first and second mating material layers interposed between the alloy and the component, and the alloy and the gyroscope body, respectively.

11. The bond structure according to claim 10 wherein the first and second mating material layers are comprised of chrome.

12. The bond structure of claim 9 further comprising a layer of the first mating material interposed between the alloy layer, and either of said components or gyroscope body.

13. The bond structure according to claim 9 wherein the first and second bonding materials are selected from the group consisting of:

gold-indium, tin-indium, gold-silver or lead silver.

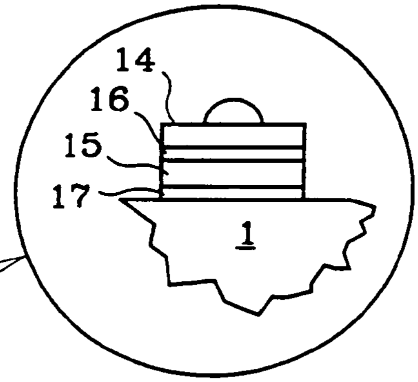

Fig. 1b

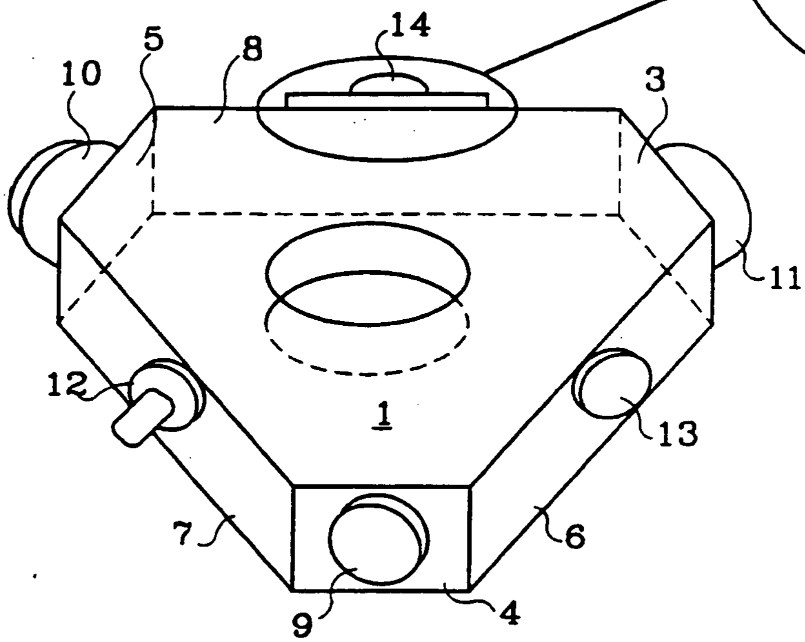

Fig. 1a

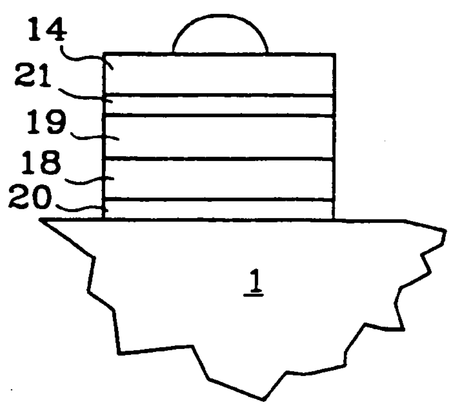

Fig. 1c

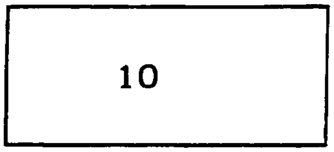

Fig.2a

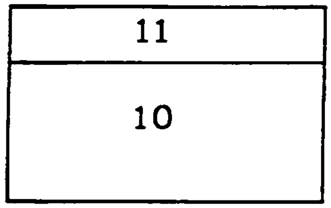

Fig.2b

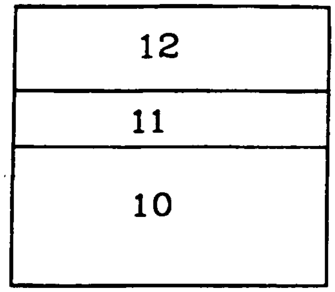

Fig.2c

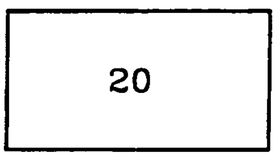

Fig.3a

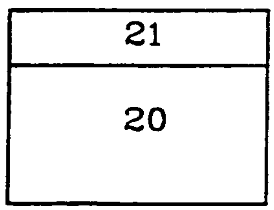

Fig.3b

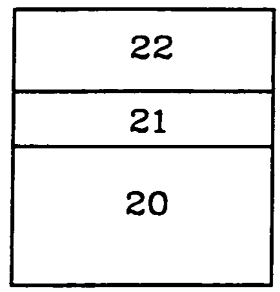

Fig.3c

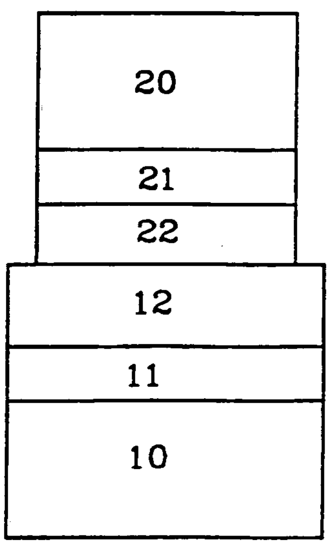

Fig.4a

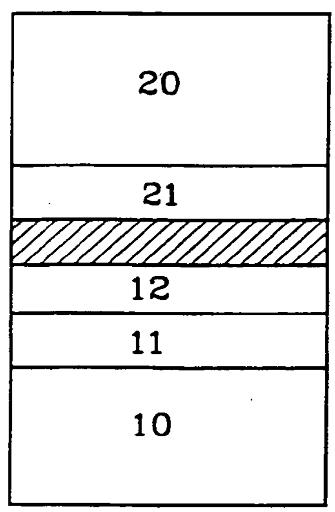

Fig.4b

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(54) Solid liquid inter-diffusion bonding for ring laser gyroscopes

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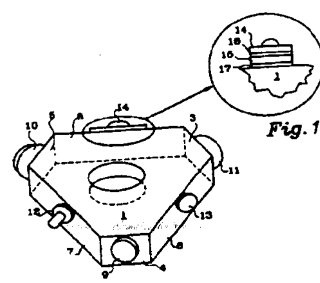

Fig. 1b

Fig. 1a

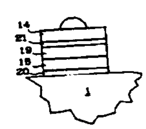

Fig. 1c

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European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 11 7031

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	GB 2 095 604 A (SPERRY LTD) 6 October 1982	1,3-5,9, 10,12,13	G01C19/66 H01S3/083
A	* column 3, line 11 - line 19; figures 2,3 *	6	
X	US 4 595 377 A (NORVELL GORDON S) 17 June 1986	1,3-5,9, 10,12,13	
A	* the whole document *	6-8	
A,D	US 5 106 009 A (HUMPSTON GILES ET AL) 21 April 1992 * the whole document *	1-13	
A,D	L. BERNSTEIN ET AL.: "Application of Solid-Liquid Interdiffusion (SLID) Bonding in Intergrated-Circuit Fabrication" TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME, vol. 236, no. 1, January 1966, pages 405-412, XP002092042 New York (US) * the whole document *	1-13	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
G01C
H01S

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	3 February 1999	Aran, D

CATEGORY OF CITED DOCUMENTS

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